SYSTEM AND METHOD FOR FUSION-ALIGNED REPROJECTION OF INCOMPLETE DATA

Field of the Invention

This invention relates generally to radiation therapy and radiology, and more particularly to a method for reconstructing incomplete patient data for radiation therapy set-up and treatment verification.

Background of the Invention

Medical equipment for radiation therapy treats tumorous tissue with high energy radiation. The amount of radiation and its placement must be accurately controlled to ensure both that the tumor receives sufficient radiation to be destroyed, and that the damage to the surrounding and adjacent non-tumorous tissue is minimized.

In external source radiation therapy, a radiation source external to the patient treats internal tumors. The external source is normally collimated to direct a beam only to the tumorous site. The source of high energy radiation may be x-rays, or electrons from linear accelerators in the range of 2-25 MeV, or gamma rays from highly focused radioisotopes such as a Co.sup.60 source having an energy of 1.25 MeV.

One form of external radiation therapy uses the precision of a computed tomography (CT) scanner to irradiate cancerous tissue because it acquires CT scans (e.g. mega-voltage CT or kilo-voltage CT) immediately before, immediately after, or during radiation delivery, with the patient on a treatment apparatus and in the treatment position. This therapy technique uses intensity modulated beams that enter the patient's body at a greater number of angles and positions than conventional therapies, thereby lessening the amount of radiation that healthy tissues are subjected to and concentrating the radiation where it is needed most, at the cancer

site(s). Essentially, the radiation field is "sculpted" to match the shape of the cancerous tissue to keep the dose of radiation to healthy tissue near the cancer low.

A radiation treatment plan may be based on a computed tomography ("CT") image of the patient. As is known in the art, a CT image is produced by a mathematical reconstruction of many projection images obtained at different angles about the patient. In a typical CT scan, the projections are one-dimensional line images indicating the attenuation of the beam by a "slice" of the patient. The actual CT data is held in a matrix wherein each row represents an angle and each column represents a distance. The matrix of data obtained in a CT scan can be displayed as a sinogram as shown in FIG. 1, or reconstructed into a two-dimensional image, as shown in FIG. 2.

In some radiotherapy systems, the oncologist views the cancerous areas on the CT image and determines the beam angles and intensities (identified with respect to the tumor image) which will be used to treat the tumor. In an automated system, such as that disclosed in U.S. Patent No. 5,661,773, and hereby incorporated by reference, a computer program selects the beam angles and intensities after the physician identifies the tumorous region and upper and lower dose limits for the treatment.

More specifically, the planning images are used to create a 3-D treatment plan of a region of interest. This region of interest is broken down into units called voxels, which are defined as volumetric pixels. Each voxel is then assigned a particular radiation dose depending on what type of tissue or other matter it contains, e.g. cancerous tissue, air, etc.

Normally, the CT image of the patient is acquired substantially before the radiation treatment to allow time for the treatment plan to be prepared. However, the position of organs or other tissue to be treated can change from day-to-day because of a variety of factors. Further,

patients move during treatment because of breathing, muscle twitching or the like. Uncertainty in the positioning of the patient with respect to the original CT image can undermine the conformality of the radiation delivery.

Thus, it is highly preferable to verify the treatment plan based on data obtained just prior to the time of treatment. The verification process can be done by techniques that compare the planning image to an image of the patient at the time of treatment.

Unfortunately, the data sets obtained on the day of treatment to be used for preparing the patient model are often incomplete. Patients that are large in size may not fit within the field-of-view (FOV) of the CT machine attached to the therapeutic equipment applying the radiation dose, and may yield an image such as that shown in FIG. 3, which shows only a portion of the image shown in FIG. 1. Not only is there a limited field of view, the data around the edges contains significant artifacts so that the image has an irregular white border and internal values are distorted. Alternatively, only a limited sample size of slices may have been obtained. There may be other limitations that result in the collection of incomplete data sets.

To resolve the problem of limited data sets in which only a portion of an image can be obtained, several scans of the patient may be made at various detector or patient positions, and then combined into a complete set. This has been done by adding together sinogram data, but requires that the imaging apparatus or patient position can be reliably modified accordingly, which is not always possible. Further, the problem of developing artifacts is still present due to the significant degree of mismatch between such data sets, and the additional handling of the patient is more costly, time intensive and can be difficult for frail patients. Moreover, the patients receive a higher dose of radiation with multiple scans than with one single scan.

Reconstruction of incomplete data sets using available techniques results in images that do not show the complete extent of the patient's body, can have artifacts and incorrect voxel values, and thus, limit the extent to which the images can be used for delivery verification, dose reconstruction and patient set-up, deformable patient registration and deformable dose registration. Accordingly, a need exists for a system and method that can solve the problems caused by limited data sets.

Summary of the Invention

The present invention relates to a method by which an incomplete CT patient data set can be combined with an existing CT patient data set to create an image of a patient that is complete and without significant artifacts.

The method includes the steps of obtaining a first sinogram data set from a patient and a second sinogram data set or image from a patient. Both data sets are converted to images, and aligned together so that statistically, there is optimal registration between the two images. The aligned or "fused" image is reprojected as a sinogram. This reprojected sinogram is compared to either the first or second sinogram to determine what data exists beyond the scope of the first or second sinogram. This additional data is added to the sinogram to which the fused sinogram was compared to obtain an augmented sinogram The augmented sinogram is converted to an image, referred to as a fusion-aligned reprojection image.

The method of the present invention is advantageous in that the availability of only one limited data sinogram/image will not affect the ability to perform accurate delivery verification, dose reconstruction, patient set-up or the like. The limited data image or "first image" is fused to a previously taken complete image or "second image." The sinogram representing the fused image is compared to the limited data sinogram, and the augmented limited data sinogram is

prepared therefrom. From the augmented limited data sinogram the fusion-aligned reprojected (FAR) image is obtained. The FAR image is used to accurately apply radiation to the treatment area, which may be positioned differently than as shown in the previously obtained complete image.

The advantages of obtaining current data at the time of treatment or even dosage verification are many. Damage to healthy tissue will be reduced, and the cancerous or diseased tissue will be more accurately targeted. These differences are especially critical in areas that have frequent internal anatomy changes, such as the torso or prostate.

While the present invention is particularly useful in the medical field, other applications are possible and references to use in cancer therapy should not be deemed to limit the application of the present invention. The present invention may be advantageously adapted for use where similar performance capabilities and characteristics are desired. These and other objects and advantages of the present invention will become apparent from the detailed description, claims, and accompanying drawings.

Brief Description of the Drawings

FIG. 1 an example of a sinogram obtained from the CT scan of a patient;

FIG. 2 is an example of a planning CT image obtained from a CT-scan sinogram similar to that shown in FIG. 1;

FIG. 3 is an example CT image with a limited field of view;

FIG. 4 is a flowchart showing the process steps of the present invention.

FIG. 5 is a schematic example of a patient CT scan;

FIG. 6 is a limited schematic view of FIG. 6, showing the limited scan portion in the center of the object, and the remaining nonscanned portion in phantom;

FIG. 7 demonstrates how the limited image of FIG. 6 is aligned with the full image of FIG. 5 through the process of fusion;

FIG. 7A show the actual alignment or "fusion" of the images from FIG. 5 and 6;

FIG. 8 is a schematic view of a fusion aligned reprojection image;

FIG. 9 is a schematic view of a full image corresponding to that in FIG. 6;

FIG. 10 is a reconstructed image of FIGS. 2 and 3 fused and aligned in accordance with the method of the present invention.

Detailed Description

A preferred method in accordance with the present invention is shown in the flowchart of FIG. 4. A limited data sinogram 50 representing the treatment area is obtained from a patient. In one preferred embodiment of the present invention, the limited data sinogram 50 is prepared near the time that the patient is receiving his or her radiation treatment. However, the limited data sinogram 50 may be obtained at any time.

The limited data sinogram 50 is reconstructed to a limited data image 52, as seen in the example of FIG. 3, and represented schematically in FIG. 6 as limited object 156. FIG. 3 contains a significant amount of artifacts such as the white irregular border 53, and some distortion of image values. By way of example, the treatment area targeted in FIG. 3 is a prostate gland. The method can be applied to images of any part of the body, or be used in veterinary or radiological applications.

A complete image 54 of the same patient and same treatment area is seen in FIG. 2, and represented schematically in FIG. 5 as object 154. Typically, this complete image 54 will have been made prior to obtaining the limited data image 52 for the purpose of treatment planning. Even if limited image 52 were taken only minutes after the complete data image 54, there are

almost always inherent differences between the location of certain organs or tissue due to patient motion or other bodily functions. If enough time has elapsed between images, weight loss or growth of certain tissue can occur.

It is noted that complete image 54 or limited image 52 need not be from CT scans, and that this technique can be generally applied to matching images from different projection imaging modalities such as magnetic resonance imaging, positron emission tomography, and single photon emission tomography. Thus, there may be misalignment or disagreement between the two images because of differing methods of data collection.

The two images shown in FIGS. 2 and 3 and represented schematically by objects 154 and 156, in FIGS. 5 and 6 have differences between them. In the actual image example of FIGS. 2 and 3, intestinal gas is shown in FIG. 3, thereby displacing the treatment target. In the schematic example, object 154 is composed of diagonals 158a and 160a and an inclusion 161a, within a frame 162a. Limited object 156 shows only corresponding diagonals 160b and 158b, and part of the inclusion designated as 161b. Thus, there is a change between diagonal 158a and 158b and only partial data for inclusion 161b.

Referring to FIG. 7, "fusion" or image registration techniques are used to align limited data image 52 with complete image 54. In the schematic example, limited object 156 is fused with complete object 154 so that statistically, there is optimal registration between the objects 154 and 156. FIG. 7 shows how the orientation of object 154 is aligned to closely match that of object 156. FIG. 7A shows diagonal 160c as the perfect registration between diagonals 160a and 160b. There is less than perfect registration between diagonals 158a and 158b. Both lines are superimposed only by way of example to show that fusion is not perfect as evidenced by the double edge 163.

Image registration or fusion may be achieved by several techniques. One such technique is known as mutual information (MI), for which a well-known algorithm has been developed. One such example of this algorithm being used to register multi-modal images is described in the following publication, incorporated herein by reference: Frederik Maes, Andre Collignon, Dirk Vendermeulen, Guy Marchal, and Paul Suetens, *Multimodality Image Registration by Maximization of Mutual Information*, Vol. 16, No. 2, IEEE Transactions on Medical Imaging, 187 (April 1997).

Extracted Feature Fusion (EFF) is another registration technique providing numerous advantages over prior art techniques. EFF is a voxel-based image registration method, wherein only extracted features of images are registered or fused. For example, a patient's bone structure usually stays the same even when a patient loses a substantial amount of weight. Therefore, the bones can in effect be extracted from each image subject to alignment, and then registered using statistical methods. In the simple example of FIG. 5, diagonal 160a and frame 162 may represent bone or tissue that remains relatively unchanged over time. Therefore, only these relatively static features might be selected for fusion, while other features that are more dynamic, perhaps diagonals 158a,b and inclusion 161a,b, need not be included in the registration calculations.

The benefits of registering only an extracted portion of an image are reduced calculation times, improved accuracy, and more clearly defined goals for alignment in cases where the patient has significantly changed in shape. The benefits arise from the registration of fewer data points, which in this case are voxels. The total processing time is generally proportional to the number of points selected, so reducing that number from the size of the entire three-dimensional image set to a subset of points meeting certain criteria (e.g. voxels that represent bone or do not represent air) will typically reduce calculation times. This reduction of voxels can provide more

accurate results than other methods of reducing the number of voxels for MI techniques, such as regular down-sampling.

Other image registration techniques include manual fusion, alignment using geometric features (e.g. surfaces), gradient methods, and voxel-similarity techniques.

Referring back to FIG. 4, the aligned or transformed complete image 56 is reprojected as a sinogram 58. The data for sinogram 58 is once again in a matrix wherein each row represents an angle, and each column represents distance. The data matrix of the reprojected sinogram is compared to the data matrix for limited data sinogram 50 to determine what data is missing from the limited sinogram. This is now possible because the complete sinogram is in alignment with the limited sinogram.

The approximation of the missing sinogram data from the reprojected, fusion aligned version of image 154 is added to the limited sinogram 50 to create an augmented limited data sinogram, or augmented sinogram 60. The augmented sinogram 60 is reconstructed to a fusion aligned reprojection image (FAR image) 62 that is an approximation of what the complete image would have looked like at the time the limited data image was obtained. The FAR image 62 is represented schematically in FIG. 8. Frame 162 is the same as in FIG. 5, and diagonals 158c, 160c and inclusion 161c are now complete. This can compared to the object 168 in FIG. 9, which represents the image that would have been taken at the time of treatment if it were possible to obtain a complete image. The fact that the outer regions 170 of diagonal 158d are not the same as diagonal 158c is not critical to the invention. FIG. 10 represents a reconstructed image obtained by combining FIGS. 2 and 3 in accordance with the method of the present invention. It can be seen that slight artifacts such as the faint ring 180 can result. However, such artifacts are insignificant because they do not impair the conspicuity of the important structures

in the field of view, nor do they noticeably detriment dose calculations or other processes that utilize these images.

The reconstructed image obtained from method of the present invention can then be used for patient setup (positioning the patient prior to delivery), dose registration (changing delivery patterns to compensate for patient position or tumor shape changes), delivery verification (using a signal measured at an exit detector to compute energy fluence directed toward a patient), deformable patient registration and deformable dose registration (using anatomical, biomechanical and region of interest data to map changes in the patient's anatomy between each fraction, a reconstructed dose is mapped to a reference image to obtain a cumulative dose).

It will be understood to those of ordinary skill in the art that other methods of comparing images may be used including, for example, those which would recognize changes beyond rigid body translation or rotation.

Although the invention has been herein shown and described in what is perceived to be the most practical and preferred embodiments, it is to be understood that the invention is not intended to be limited to the specific embodiments set forth above. It is recognized that modifications may be made by one of skill in the art of the invention without departing from the spirit or intent of the invention and therefore, the invention is to be taken as including all reasonable equivalents to the subject matter of the appended claims.